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LONGITUDINAL Λ POLARIZATION IN POLARIZED SEMI-INCLUSIVE DIS[*]

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We calculate, within pQCD parton model at leading orders, the expression of the longitudinal polarization of Λ baryons produced in polarized semi-inclusive DIS, including weak interaction effects. We present some numerical estimates in few cases for which data are or will soon be available and discuss how to gather new information on polarized fragmentation functions.

1 Introduction

The polarization of spin 1/2 baryons inclusively produced in polarized Deep Inelastic Scattering processes may be useful, if measurable, to obtain new information on polarized distribution and fragmentation functions.

Because of their parity violating weak decay and their self-analysing polarization, Λ hyperons are an ideal laboratory for this study. Moreover, since in a non-relativistic quark model the spin of a Λ is carried by the strange quark, any signal of an up (or down) quark spin contribution would reveal a novel hadron spin structure.

From the experimental side, NOMAD collaboration have recently published new results [1] on the Λ polarization in ν_μ charged current interactions; more data might soon be available from high energy neutral current processes at HERA, due to electro-weak interference effects. It is then timely to perform a systematical and comprehensive study of weak interaction contributions to the production and the polarization of Λ baryons in as many as possible DIS processes. We stress that such contributions are an important source of new information, due to the natural neutrino polarization and to the selected couplings of W's to pure helicity states.

In our calculations we take into account leading twist factorization theorem, Standard Model elementary interactions at lowest perturbative order and

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LO QCD evolution only.

2   Charged current processes, $\nu p \to \ell \Lambda^\uparrow\ X$

For these processes, there exist two possible elementary contributions, corresponding to the interactions: $\nu d(s) \to \ell^- u$ and $\nu \bar{u} \to \ell^- \bar{d}(\bar{s})$. Neglecting quark masses one finds that there is only one non-zero helicity amplitude for each of them, corresponding to the following elementary cross-sections: $d\hat{\sigma}^{\nu q}_{--}$ and $d\hat{\sigma}^{\nu \bar{q}}_{-+}$. For longitudinally ($\pm$ helicity) polarized protons we have [2]

$$P^{(\pm)}_{[\nu,\ell]}(B;x,y,z) = -\frac{[d_\mp + R\,s_\mp]\,\Delta D_{B/u} - (1-y)^2\,\bar{u}_\pm\,[\Delta D_{B/\bar{d}} + R\,\Delta D_{B/\bar{s}}]}{[d_\mp + R\,s_\mp]\,D_{B/u} + (1-y)^2\,\bar{u}_\pm\,[D_{B/\bar{d}} + R\,D_{B/\bar{s}}]} \tag{1}$$

and

$$P^{(\pm)}_{[\bar{\nu},\ell]}(B;x,y,z) = \frac{[\bar{d}_\pm + R\,\bar{s}_\pm]\,\Delta D_{B/\bar{u}} - (1-y)^2\,u_\mp\,[\Delta D_{B/d} + R\,\Delta D_{B/s}]}{[\bar{d}_\pm + R\,\bar{s}_\pm]\,D_{B/\bar{u}} + (1-y)^2\,u_\mp\,[D_{B/d} + R\,D_{B/s}]}\,, \tag{2}$$

where $(D_{B/q})\,\Delta D_{B/q}$ are the (un)polarized fragmentation functions (FF) and $R \equiv \tan^2\theta_C \simeq 0.056$. In the case of unpolarized protons one replaces the polarized parton distributions q_+ and q_- with $q/2$.

When a Λ baryon is produced (rather than a $\bar{\Lambda}$), we can neglect terms which contain both $\bar{q}$ distributions and $\bar{q}$ fragmentations and we simply have:

$$P^{(\pm)}_{[\nu,\ell]}(\Lambda;z) \simeq P^{(0)}_{[\nu,\ell]}(\Lambda;z) \simeq -\frac{\Delta D_{\Lambda/u}}{D_{\Lambda/u}}\,, \tag{3}$$

$$P^{(\pm)}_{[\bar{\nu},\ell]}(\Lambda;z) \simeq P^{(0)}_{[\bar{\nu},\ell]}(\Lambda;z) \simeq -\frac{\Delta D_{\Lambda/d} + R\,\Delta D_{\Lambda/s}}{D_{\Lambda/d} + R\,D_{\Lambda/s}}\,, \tag{4}$$

and the polarizations, up to QCD evolution effects, become functions of the variable z only.

Eqs. (3) and (4) relate the values of the longitudinal polarization $P(\Lambda)$ to a quantity with a clear physical meaning, *i.e.* the ratio $C_q \equiv \Delta D_{\Lambda/q}/D_{\Lambda/q}$; this happens with weak charged current interactions – while it cannot happen in purely electromagnetic DIS [3] – due to the selection of the quark helicity and flavour in the coupling with neutrinos. In Fig. 1 (left) some predictions for $P(\Lambda)$ and $P(\bar{\Lambda})$ are shown (see also Sec. 4).

Notice that a comparison of $P(\Lambda)$ for ν and $\bar{\nu}$ beams might give information on the ratios C_q; for example, the same value of C_q for all flavours would result in $P_{[\nu,\ell]}(\Lambda) = P_{[\bar{\nu},\ell]}(\Lambda)$. On the other hand, largely different values of $P_{[\nu,\ell]}$ and $P_{[\bar{\nu},\ell]}$ would certainly indicate a strong $SU(3)$ symmetry breaking in the fragmentation functions.

3 Neutral current lepton processes, $\ell p \to \ell \Lambda^\uparrow \; X$

In this case there are four non-zero independent helicity amplitudes for the elementary processes $\ell q \to \ell q$; both weak and electromagnetic interactions are to be included at the amplitude level. The complete (long) formulae [2] are not shown here; some interesting results are displayed in Fig. 1 (right), see also Sec. 4, where we plot the Λ polarization vs. x (averaged over z) for longitudinal polarized leptons and unpolarized protons. These results test the dynamics of the partonic process and in particular the contribution of electro-weak interferences, in a neat and unusual way. The differences between positron and electron beams are entirely due to electro-weak effects; this is well visible at large x, where the curves for e^+ and e^- differ sizeably. Moreover for unpolarized leptons and protons the longitudinal Λ polarization is non-zero [2] only due to parity violating weak contributions.

4 Numerical estimates

The polarization values depend on the known Standard Model dynamics, on the rather well known partonic distributions, and on the quark fragmentation functions. The latter are not so well known and a choice must be made in order to give numerical estimates or in order to be able to interpret the measured values in favour of a particular set.

Unpolarized Λ FF are determined by fitting $e^+ e^- \to (\Lambda + \bar\Lambda) + X$ data, sensitive only to singlet combinations, like $D_{\Lambda/q} + D_{\Lambda/\bar q} \equiv D_{(\Lambda+\bar\Lambda)/q}$. Polarized Λ FF are obtained by fitting the scarce data on Λ polarization at LEP, sensitive only to non-singlet combinations like $\Delta D_{\Lambda/q} - \Delta D_{\Lambda/\bar q} \equiv \Delta D_{\Lambda/q}^{val}$. In both cases flavour separation has to rely on models.

We adopt three sets of FF, denoted as scenarios 1, 2 and 3, and derived [4] from fits to $e^+ e^-$ data for which $\Delta D_{\Lambda/u(d)} \simeq N_u \, \Delta D_{\Lambda/s} \; (D_{\Lambda/u(d)} = D_{\Lambda/s})$. The three scenarios differ for the relative contributions of the strange quark polarization to Λ polarization: $N_u = 0$, $N_u = -0.2$ and $N_u = 1$ for scenarios 1, 2 and 3 respectively and are well representative of possible spin dependences.

Equipped with unpolarized FF into $\Lambda + \bar\Lambda$ and with separate polarized FF into Λ and $\bar\Lambda$, we can define the following computable quantities:

$$P^*(\Lambda) \equiv \frac{d\sigma^{\Lambda_+} - d\sigma^{\Lambda_-}}{d\sigma^{\Lambda+\bar\Lambda}} = \frac{P(\Lambda)}{1+T}, \quad P^*(\bar\Lambda) \equiv \frac{d\sigma^{\bar\Lambda_+} - d\sigma^{\bar\Lambda_-}}{d\sigma^{\Lambda+\bar\Lambda}} = \frac{T\,P(\bar\Lambda)}{1+T}, \quad (5)$$

where $T = d\sigma^{\bar\Lambda}/d\sigma^{\Lambda}$. Eqs. (5) allow to compute the values of $P(\Lambda)$ and $P(\bar\Lambda)$ provided one can compute or measure the ratio T. Notice that P is always larger in magnitude than P^*.
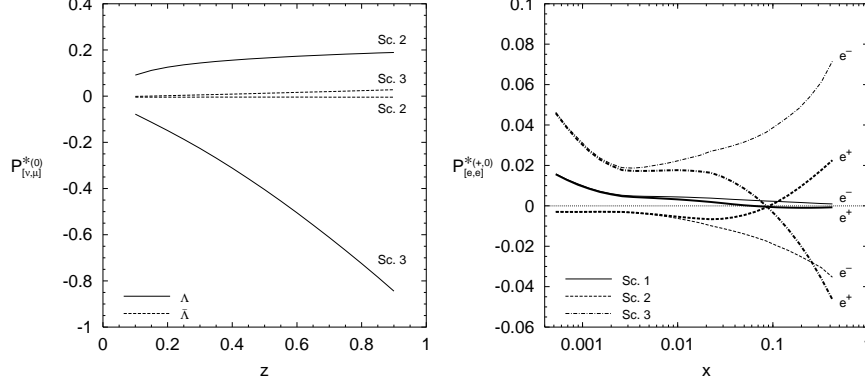
Figure 1: Left: $P^{*\,(0)}_{[\nu,\mu]}$ as a function of z, with a kinematical setup typical of NOMAD experiment at CERN. Results with scenario 1 are almost negligible. Since $\langle x \rangle$ is large for this kinematical configuration, we expect $T = d\sigma^{\bar\Lambda}/d\sigma^{\Lambda} \ll 1$ and, as a consequence, $P^{(0)}_{[\nu,\mu]}(\Lambda) \simeq P^{*\,(0)}_{[\nu,\mu]}(\Lambda)$, while $P^{(0)}_{[\nu,\mu]}(\bar\Lambda) \gg P^{*\,(0)}_{[\nu,\mu]}(\bar\Lambda)$. Right: $P^{*(+,0)}_{[e,e]}$ for Λ hyperons, as a function of x. The kinematical setup is typical of HERA experiments at DESY. Since $T \ll 1$ at large x and becomes comparable to unity at very low x, we expect, correspondingly, $P_{[e,e]}(\Lambda) \simeq P^{*}_{[e,e]}(\Lambda)$ and $P_{[e,e]}(\Lambda,\bar\Lambda) \simeq 2\,P_{[e,e]}(\Lambda,\bar\Lambda)$.

We conclude by pointing out how this comprehensive study of the polarization of Λ's and $\bar\Lambda$'s can help to gather new information about polarized FF and to test fundamental features of electro-weak elementary interactions.

1. NOMAD Collaboration, P. Astier *et al.*, *Nucl. Phys.* B **588**, 3 (2000); e-Print Archive: hep-ex/0103047.
2. M. Anselmino, M. Boglione, U. D'Alesio and F. Murgia, e-Print Archive: hep-ph/0106055, and references therein.
3. M. Anselmino, M. Boglione and F. Murgia, *Phys. Lett.* B **481**, 253 (2000).
4. D. de Florian, M. Stratmann and W. Vogelsang, *Phys. Rev.* D **57**, 5811 (1998).